RISING WATERS

Pre-Visit Activity 3: Mathematical Model for Storm Surge

Directions: You will need a calculator and scrap paper for these equations. Please answer all questions on the provided answer sheet.

Equations for the Simple Model

We want to predict the storm surge, which we will denote by the Greek letter eta (η). We assume the coast can be represented as a one-dimensional section that extends offshore. The storm will approach directly to the coast and have a wind speed of *W*. The continental shelf will have a width *L* and an average depth *h*.

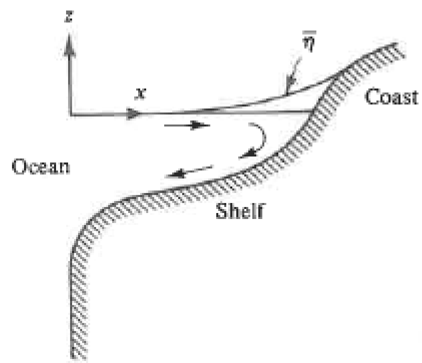

Figure 9: Simplified model for storm surge. The storm approaches from the ocean and increases the storm surge η at the coast. Figure from Dean and Dalrymple, 1992.

Given a wind speed *W*, we can compute a drag coefficient *k*:

$$k = 1.2 \cdot 10^{-6} + 2.25 \cdot 10^{-6}\left(1 - \frac{5.6}{W}\right)^{2}$$

which represents the effect of the storm winds on the surface of the ocean. The higher the drag coefficient *k*, the more the storm is pushing on the water. We can also compute the storm factor *A*:

$$A = \frac{1.15LkW^{2}}{gh^{2}}$$

in which $g = 9.81$m/s^2 is gravity. The storm factor *A* has the combined effects of the storm itself (represented by the drag coefficient *k* and the wind speed *W*) and the coast (represented by the shelf width *L* and average depth *h*). The higher the storm factor *A*, the more the coast is vulnerable to storm surge.

We can compute the storm surge at the coast:

$$\eta = h\left(\sqrt{1+2A}-1\right)$$

which gives storm surge η in units of meters at the coastline.

Example for Hurricane Florence

As an example, consider again for Hurricane Florence in 2018. We found already the input factors: the shelf width was about 27 nautical miles, the average depth was about 50 feet, and the storm wind speeds were about 90 miles per hour. First, we need to convert these input factors into metric units:

- Shelf width:

  L = (27 nautical miles) * (1852 meters per nautical mile) = 50,000 m

- Average depth:

  h = (50 feet) * (0.3048 meters per feet) = 15 m

- Wind speed:

  W = (90 miles per hour) * (0.447 m/s per mph) = 40 m/s

Then, using those input factors in metric units, we can predict the storm surge at the coast. The steps are:

1. Compute the drag coefficient *k*:

$$k = 1.2 \cdot 10^{-6} + 2.25 \cdot 10^{-6}\left(1 - \frac{5.6}{40}\right)^{2} = 2.86 \cdot 10^{-6}$$

2. Compute the storm strength *A*:

$$A = \frac{1.15LkW^{2}}{gh^{2}} = \frac{1.15\,(50000)(2.86 \cdot 10^{-6})(40)^{2}}{9.81(15)^{2}} = 0.119$$

3. Compute the storm surge η at the coast:

$$\eta = h\left(\sqrt{1+2A}-1\right) = (15)(\sqrt{1+2(0.119)}-1) = 1.7$$

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The storm surge at the coast is predicted to be η = 1.7 m, or about 5.5 ft. This prediction is close to what actually happened -- NOAA measured a storm surge of 1.2 m at a gauge near Wrightsville Beach, North Carolina. Our simple model was too high by about 0.5 m (or 1.5 ft).

There are plenty of reasons why the simple model has an error. It does not include all of the factors that influence storm surge, and we were imprecise in our values for the few input factors we did include. But even with those errors, the simple model is useful because of its simplicity. We don't need a complex model like SLOSH or ADCIRC to predict the surge for an approaching storm. All we need are three input factors (wind speed, shelf width, average depth) and three equations.

Discussion questions:

1. For the example during Hurricane Florence, the simple model was too high by about 0.5 m. Is this a good prediction? Why or why not?
2. For the example during Hurricane Florence, how can we improve our input factors to get a better prediction? If we use a different value for the average depth, then will the prediction be better or worse?
3. For the storm you selected in the previous section, and using the input factors you found for that storm, predict the storm surge at the coast. Do you believe your answer?
4. Would you trust this simple model for a storm approaching your home?
5. If you could add one more input factor to this simple model, what would it be and why?

Additonal Resources

- Hurricanes: Science and Society, "Numerical Models of Storm Surge, Wave, and Coastal Flooding."
- National Hurricane Center, "Introduction to Storm Surge."
- National Ocean Service, "What is Storm Surge?"
- SECOORA, "The Surge of the Storm."